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The Digital Transition for a Sustainable Mobility Regime? A Long-Run Perspective

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Abstract: New Information and Communication Technologies (ICTs) have been praised to massively transform our economies, and to be the foundation of a new and more sustainable mobility regime. But will they? And if so, how could ICTs help building it? While the newest ICTs such as the internet are in some ways unique, in other respects they have historical predecessors (such as the telegraph and the telephone) that are worth considering. This paper reviews the literature and shows that 'older' ICTs have transformed our mobility regime in significant and unpredictable ways. In particular, they have supported and made more efficient new transport modes, contributed to the geographical concentration and dispersion trends of economic activities and changed how and how much we connect to our families and friends. ICTs can help building more sustainable mobility e.g., by making transport more efficient or reducing mobility demand in some cases, but overall the interactions between mobility and ICTs turn out to be important, diverse and complex.

Keywords: Green deal, ICT, Digital transition, Mobility, Technological transformation, Innovation.

JEL Codes: N10, N90, O14, O18, O33, R41, R42.

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1. Introduction

In its European Green Deal, the EU has set itself the target to become climate-neutral by the year 2050 (European Commission 2019). It has further boosted its ambitions as a reaction to Russia's war on Ukraine, initiating the REPowerEU plan which, according to President Von der Leyen, "will be the speed-charging for our European Green Deal", mobilising around €300 billion (European Commission 2022a).

To better understand the challenges of moving towards a more sustainable economy, many authors have recently used history and analyses that provide a long-term perspective (e.g., Rifkin 2011, Perez 2014). The ongoing Ukraine war, COVID-19 crisis and the recent Great Recession, i.e. the economic and financial crises that started in in the late 2000s, are the newest in a series of major economic crises over the last centuries (e.g., Temin 2010, Wilenius and Casti 2015, Lieberman 2018). At the same time, they are the most important crises since the Great Depression. In light of these analyses, the Ukraine war combined with the COVID-19 crisis may lead to a fundamental restructuring of our economy, and we may be at the beginning or in the middle of a new innovation "wave" that will help build a sustainable world.

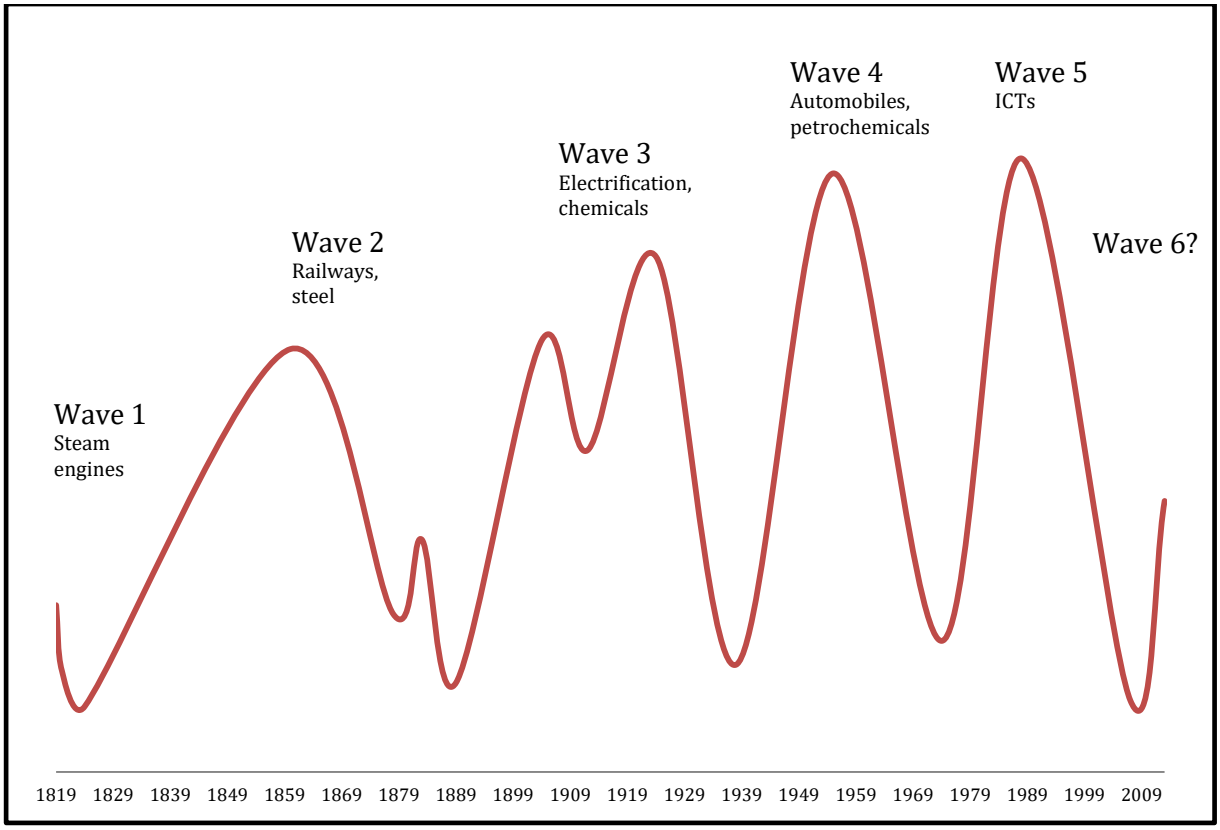

Figure 1. Long-run waves of innovation
Source: adapted from Wilenius and Casti (2015).

More specifically, there have been five (Kondratieff 1926) innovation waves during the last 200 years (e.g., Diebolt 2005, 2012, 2021, Freeman 1996, Kleinknecht 1987, Mensch 1977, Schumpeter 1939, Wilenius and Casti 2015). They can be illustrated as shown in Figure 1. The first one occurred between 1780 and 1830 and was related to the development and improvements of the steam engine and the textile industry, while the second lasted until 1880 and was associated with the construction of railways and the steel industry. The third one spanned 50 years (up to 1929) and was driven by

innovations in electricity and chemicals, while the fourth went from 1930 to around 1970, a time characterised by the surge of automobiles and petrochemicals. Finally, the most recent fifth wave lasted in this reading until 2009 and saw the rise of Information and Communication Technologies (ICTs). Evidently, all waves were characterised by major technological innovations that led to upswings but also by ending in major crises. For example, the most recent ones are still well remembered: the Great Depression after 1929, the Oil Crises of the 1970s and the Great Recession of the 2000s and 2010s.

Diebolt (2002) summarized this long run trend in the frame of a Social Structure of Accumulation (SSA) approach. In fact, SSA provides an original way of analysing the structure and development of capitalist economies and societies. The term SSA refers to the complex of institutions which support the process of capital accumulation. The central idea of the SSA approach is that a long period of relatively rapid and stable economic expansion requires an effective SSA. The SSA is made up of political and cultural institutions as well as economic ones. The institutions comprising an SSA can be both domestic and international arrangements. Domestic institutions may include the state of labour-management relations, the organisation of the work process, the character of industrial organisation, the role of money and banking and their relation to industry, the role of the state in the economy, the line-up of political parties, the state of race and gender relations and the state of the educational system. International institutions may concern the trade, investment, monetary-financial and political environments.

The development of the SSA approach was motivated by at least three analytical concerns: historical, comparative, and programmatic. An historical concern suggests that individual economic systems, and the world system of which each is a part, go through periodic booms and periodic times of trouble. These alternating periods have been called 'long waves'. These long waves appear to be associated with the bunching of institutional changes, which take place in a discontinuous manner. Such patterns require an explanation.

The SSA approach is not directed only at the problem of uneven economic expansion and discontinuous institutional change over time. It is also concerned with differences between the economic systems of various nations. The comparative concern suggests that, contrary to the view of traditional neoclassical economics, institutions and social structure make a difference to the functioning of economic systems. While Japan, Germany, the United States, Sweden and South Africa are all market-oriented economies, their structures and performances also differ considerably from one another. To explain these different outcomes, we need a theory that incorporates the institutional differences between countries.

A programmatic policy concern asks how new institutions develop and are consolidated. Why do some attempts to reform and transform the economy and social structure meet considerable success, while others have only a limited impact, and yet others fail completely?

In line with this reasoning, for some authors, the next and sixth innovation wave is driven by sustainable technologies and practices, and would logically lead to a more sustainable economy. Demailly and Verley (2013) have shed some light and some doubts on this potential transformation. For others we are still in the fifth and thus the ICTs wave – peer-to-peer exchange platforms, apps for smart phones and social media,

big data and the 'Internet of things', etc. – that has the power to reshuffle our production and consumption modes and to build a sustainable economy (GeSI 2012). Teleworking has also expanded in many areas during the COVID-19 crisis (Pouliakas 2020, Flisi and Santangelo 2022), which has led to lower mobility needs for many employees (Kong et al 2022). Widespread teleworking will (at least partly) remain in the 'new normal' in the future in many economic sectors.

However, if new ICTs raise opportunities to reduce the ecological footprint of our economies, they also create many challenges (e.g., Berkhout and Gertin 2001, Marz 2022), if only due to the footprint of producing these technologies (e.g., Zhang and Xie 2015). Moreover, whereas the literature focuses on the impact of the newest ICTs such as Internet, these technologies have historical predecessors such as the telegraph or the telephone that have also generated great expectations and have transformed their contemporaneous society.

This paper provides a literature review whose objective is twofold:

- First, we investigate how old (telegraph, telephone) and new ICTs ("Internet") have and keep on transforming our mobility modes (i.e. how we move) and patterns (i.e. how much and what for). We aim to provide a comprehensive overview of the linkages between ICT and mobility, for old and new technologies.

- Second, we illustrate how ICT can help – or not – building new (sustainable) mobility, through more efficient modes of transport or through reduced demand for mobility.

Mobility looks like a good case study as it faces many sustainability challenges: energy scarcity and climate change mitigation, local pollution and noise, important needs for space in cities, biodiversity impact of transport infrastructures, etc. On the energy and climate dossiers alone, it is worth noting that the mobility (i.e. transport) sector accounted for 29 % of all CO_2 emissions in the EU in 2018 (European Parliament 2020). Therefore, the traditional approach – which puts, for example, traffic and motorised transport into its focus, relies on forecasting, uses economic evaluation and sees travel simply as a derived demand – appears not to work well anymore in such an environment (see Table 1). The alternative, sustainable mobility approach is e.g., more people-centred, considering all modes of transport and a variety of environmental and social concerns, thus addressing all the challenges we have just mentioned. To progress towards this mobility regime, the Avoid, Shift, Improve (ASI) framework has now been widely adopted. It is a structure with which the full range of sustainable mobility options can be adopted (Banister 2014). These options include substituting or not making trips, shortening trip lengths through land use planning, the use of public transport, walk and cycle, and, finally, increasing fuel efficiency.

Traditional approach	**Sustainable mobility**
Physical dimensions	Social dimensions
Mobility	Accessibility
Traffic focus	People focus
Large in scale	Local in scale
Street as a road	Street as a space

Traditional approach	Sustainable mobility
Motorised transport	All transport modes
Forecasting traffic	Visioning on cities
Modelling approaches	Scenario development and modelling
Economic evaluation	Multicriteria analysis (taking account of environmental and social concerns)
Travel as a derived demand	Travel as a valued activity and a derived demand
Demand-based	Management-based
Speeding up traffic	Slowing movement down
Travel time minimisation	Reasonable travel times and travel time reliability
Segregation of people and traffic	Integration of people and traffic

Table 1. Traditional and sustainable mobility approaches.
Source: adapted from Banister (2008).

In short, our literature review highlights that ICTs, from the telegraph to the Internet, have had important impacts on mobility, but that their relationships are diverse and complex. ICTs have transformed and keep on transforming our mobility modes and patterns in very different ways, but also in very unpredictable ways. We also highlight that ICTs, old or new, are contributing to radically transform our mobility but that this is not automatically to the benefit of sustainability: there are conditions and consequently choices to be made and policy interventions to be designed.

Therefore, we consider in this paper the history of ICT and mobility in order to understand or at least illustrate the nature and the intensity of the linkages of the two. History here is used to exemplify how diverse and complex are the linkages between ICT and mobility and how they can contribute or not to more sustainability.

Section 2 investigates the relationships between ICT and mobility from a quite conceptual perspective and provides a typology of the various promises and changes that new ICT may support towards a more sustainable mobility. Section 3 provides a review of the historical literature at the crossroads of ICT and mobility, and studies the impacts of the telegraph and the telephone on mobility. Section 4 digs into the promise that more communication (i.e. information transport) means less mobility (passenger transport) and investigates how new ICTs are transforming the ways we access work, services or leisure. We conclude in section 5.

2. Relationship between ICT and mobility

Taking a joint look at ICT and mobility is a meaningful approach. In fact, both are closely intertwined. ICT can be considered a broader definition of communications. Similarly, mobility relates to transportation. Accordingly, Thrift (1990, p. 453) states that "transport and communication cannot be split apart. Each relies on the other in all manner of ways".

Mokhtarian (1990) names four core dimensions in which they are related.

- First, using a conceptual dimension, ICT is a form of transportation (see also Choo and Mokhtarian 2007). More specifically, ICTs transport information, while transport itself transports individuals and objects. However, it is an asymmetrical relationship because every form of communication intrinsically transports something, while transportation does not always have the goal of communication.
- Second, the physical infrastructure of ICT and transportation are often combined. That is, the new construction of ICT networks have often been superimposed on the transport networks that already existed. The telegraph and railways are a typical example of this phenomenon (we come back to this example below).
- Third, from an analytical perspective, both ICT and transport are characterised by their network structure. The Internet is the most recent network structure, but the same rule also applies to other ICT and transport technologies.
- Finally, there has been an interesting correspondence for the evolution of regulations for ICT and transportation. At first, both large parts of ICT and transport sectors were deemed to be natural monopolies. In many cases, a state company ran the ICT or transport network (e.g., railways). However, this point of view changed over time, and deregulation was the consequence.

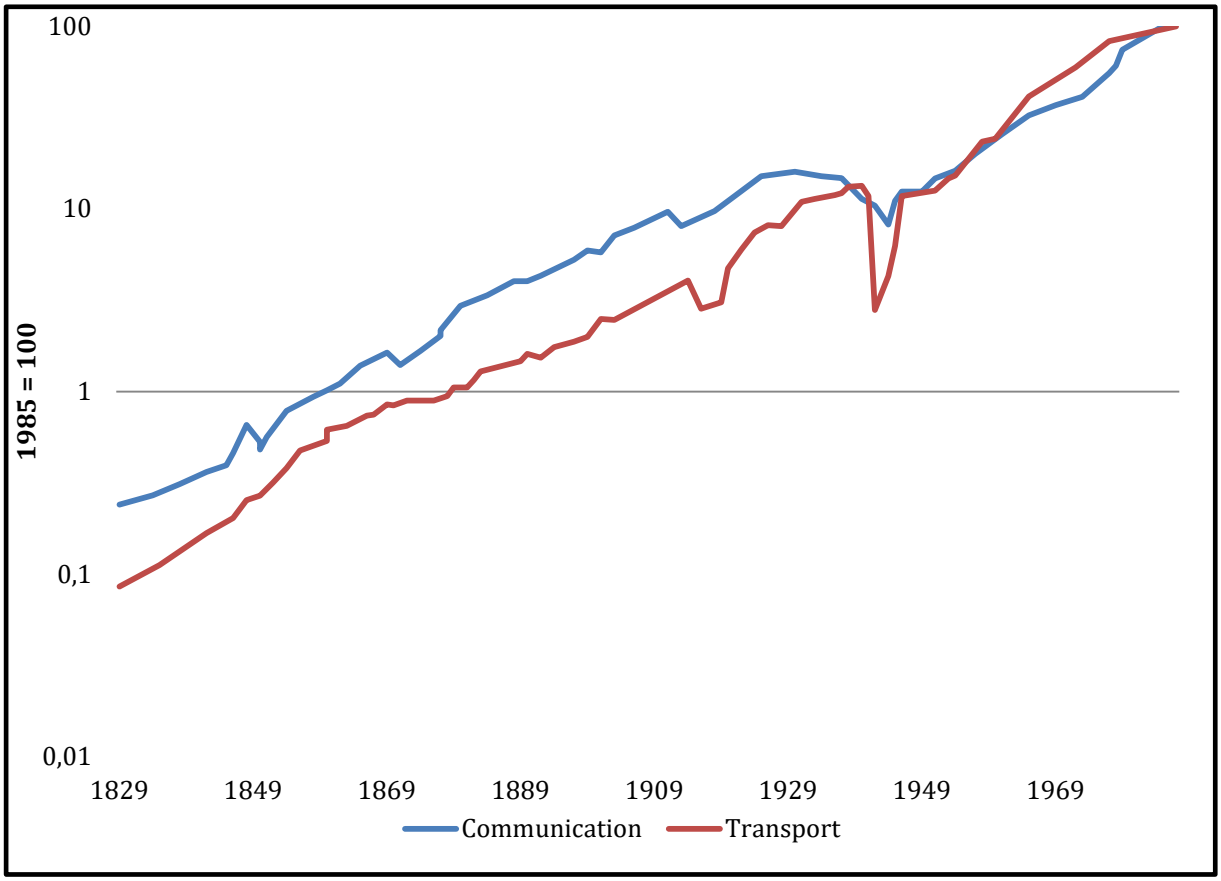

Figure 2. Growth of (passenger) transport and communication, France
Source: adapted from Grübler (1990).
Note: Passenger transport is measured as total transport passenger-km, communication is measured as total number of transmitted messages. Both trends are indexed to 100 in 1985.

These dimensions show the inherent relationship between ICT and transportation and confirm the relevance of considering both in a mutual framework. The relationship should not be exaggerated however: both communication and transportation have grown over the past centuries, as shown in Figure 2, and these trends are intertwined but up to a certain extent only.[4] The increase in mobility for example is driven by factors that go much beyond communication, if only by the speed of transportation systems, allowing for example Americans to travel 50 kilometres per day today versus only 50 metres in 1800 (Urry 2007, Mok et al 2010).

As regards "new" ICT, it turns out that the promises for sustainable mobility are numerous. One may distinguish between three positive changes that ICT may bring to the current mobility regime (see Miroux and Lefèvre 2012, Cohen-Blankshtain and Rotem-Mindali 2014): less physical transport needed, a greater efficiency of the transport system, and a shift towards alternatives transport modes.

From kilometres to bytes. A first prominent and overarching promise of ICT for mobility is that it will lead to a 'death of distance'. In fact, one hypothesis is that ICTs such as telecommuting, videoconferencing or e-commerce will be a major step forward in reducing the dependence on the location in space for individuals, and consequently may imply less traffic because an important number of transactions do not need physical transportation anymore. The exchange and transportation of bits and bytes would then substitute physical mobility of people and goods with, allegedly, much lower environmental effects than their physical counterparts. ICTs would help building a 'dematerialised economy' (or at least dematerialising economy).

A greater efficiency of the transport system. The transport system may use the newest ICTs to optimise the management and flow of transport. In particular ICTs are deemed to reduce congestion problems hence reduce emissions and waste energy. Congestion problems exist notably in cities, but also on major motorways in almost any country and the increased use of ICTs may allow drivers to avoid these problems for example by informing individuals about the current traffic situation and by indicating alternative routes. Ultimately, automated cars and highways would optimise routes themselves. ICTs are also expected to increase the efficiency of the public transport system through better management of flows, better information systems for passengers or more efficient pricing and payment methods. Lower costs of operation, better service and higher safety for travellers are seen as significant side effects.

Modal shift. Finally, ICTs may support a modal shift from individual and car-based transport systems towards more collective modes. Not only increasing public transport efficiency may lead to higher use, but ICTs could also support new modes of transportation such as ride-sharing or car-sharing and help switch from one mode of transport to another one (through better information or "single ticket" systems).

[4] It is evident from the figure that the First and Second World Wars clearly affected passenger transport and, to a lower relative extent, communication in France, as there are notable decreases between 1914 and 1918 and between 1939 and 1945 (see Grübler 1990).

3. Historical detour

In many cases, historical means of communication were implicitly used to substitute for transportation (see Mokhtarian 2009). The first means of communication were related to sound and sight, such as trumpets and flags. By using these forms of communication, it was not necessary anymore to travel to another location. However, the visual and auditive capacities of humans are quite limited, so that these very early "ICTs" could only facilitate communication for relatively short distances. The invention of writing and later printing radically modified the possibilities to communicate. Communication became further de-personalised, as the sender of communication did not need to be in contact with the receiver of the communicated information in space or time. However, transport and communication were still closely coupled, as a physical messenger was always necessary (Mok et al 2010). Finally, the last step in forms of communication has been through electronic means such as the telegraph, the telephone and more recently the Internet[5].

Below we draw some insights from the historical literature on the telegraph and the telephone. How have these technologies transformed or helped transforming our transports modes? Have they led to reduced demand by concentrating activities, or to more demand for transport by dispersing them? Have they "pushed" individuals to travel more or less? Obviously, there are no clear-cut answers. Therefore, we first note that the history of ICT is full of promises, failures and unexpected successes.

3.1 A history of promises, failures and unexpected successes

The history of the telegraph and the telephone is full of promises – and sometimes fears, that did not materialize. Standage (1998) shows that many believed that the telegraph would change the existing socio-economic regime. For example, contemporary observers expected a large democratisation of society, the breaking up of class barriers and a reduction in loneliness. Some contemporaneous authors also claimed the "annihilation of time and space" (Morus 2000, p. 456).

Geels and Smit (2000, p. 868) note that the telephone introduction was "accompanied by vehement discussions about its impact on social life. Although transportation itself was not so much an issue in these discussions, some people expressed their fear that future generations might remain indoors, maintaining necessary contacts only via the telephone". These authors also highlight that speculation about automated cars and highways was already around in the 1930s. In its Futurama exhibition General Motors toured visitors around through scale models, demonstrations and films, showing a future transportation system where almost everything would operate automatically.

[5] It is worth insisting on a key difference among them and with the newest ICTs. The telegraph was the first of these grand inventions of modern ICT: for the first time communication without face-to-face contact was possible. "In a historical sense, the computer is no more than an instantaneous telegraph with a prodigious memory, and all the communication inventions in between have simply been elaborations on the telegraph's original work" (Marvin 1988, p. 3). However the telegraph was not yet a very democratic ICT, if only because its use was quite expensive. Thus, it was mostly employed by organisations such as governments and businesses, and only used for private communication in the case of major life events (Pred 1973, Mok et al 2010). The telephone and later the Internet democratised access to communication to an important extent.

After people had pushed the buttons of their vehicle, and instructed its destination, an automatic electronic system, and roads with invisible rails and radar systems would take them there.

If the history of modern ICT shows many promises that have not materialized, it is fair to say that many contemporary observers have also underestimated the fundamental impact of ICT on society. The telephone, for example, was described as merely an "electrical toy" by Western Union officials when it was first introduced to England. Moreover, the cheapness of messenger boys was seen as a formidable reason why the still relatively expensive use of telephones would not have a great impact on society and the existing communication and mobility networks (Dilts 1941, Mokhtarian 2002). History proves that these hypotheses were wrong. It is also worth noting that the telephone industry itself resisted the so-called 'trivial' use of the telephone for social calls until the 1920s (Fischer 1988) and kept focusing on commercial, industrial and even defence markets. According to Green and Adam (1998), this was strongly related to gender considerations as the main users of the telephone for social calls were women isolated at home.

3.2 ICT for a more efficient transport system

Whereas new ICTs are deemed to play a critical role in building a more efficient transport system, it turns out that older technologies such as the telegraph have played an important role in the growth of railway lines. Indeed, with increasing industrialisation and construction of the railway network, it was important to be able to control the transport network at a distance. For example, the increasing speeds of trains posed a challenge to the security of the passengers. Effective control of the transport system through the use of the telegraph was essential for the success of the railways (Spar 2001).

According to Carey (2009), the telegraph was also fundamental to standardising time as such. Historically, every city (and many villages) had its own time, calculated from the movement of the sun and the stars. In the US state Wisconsin alone, there were 39 different time zones. Clearly, this multitude of time zones created trouble when the railways arrived. Passengers did not really know when the train was supposed to arrive at their city in their time zone, and led to accidents. The speed at which information and time could be communicated through the telegraph enabled a more uniform system with the creation of standard time zones in the entire world. Thus, the telegraph allowed an impressive growth of railway lines, while the railway lines were also fundamental for the construction of the telegraph network (the telegraph lines usually followed already existing railway lines, as the ICT network was often superimposed on the transportation network , see Mokhtarian 2009).

Obviously, it is not because the literature on the telegraph insists on its linkages with railways that we should conclude that the telegraph – and more generally, ICT – support more so-called sustainable modes of transport than unsustainable ones. If this literature does not insist on the impact of the telegraph on roads, it is rather because cars and trucks were invented much later than the telegraph. Thus, one may guess that the telephone has supported as much the functioning of railways as of roads.

3.3 ICT, geography and cities

The need for transport is determined by the spatial organisation of people and firms: where people live and work, where business offices and factories are located, etc. Many authors discuss the impact of ICT on this organisation, highlighting the role that they play in the concentration or dispersion of cities. Below we present this literature. Note that the concentration of people and activities in cities does not automatically mean lower transport needs. In fact, one can imagine big and powerful "global cities" inside of countries (Sassen 2012) with shapes including highly transport-dense areas.

Do ICTs lead to a more concentrated or more dispersed organisation of firms and workers? The fact that cities exist indicates that agglomeration forces (e.g., beneficial contacts between economic actors, knowledge spillovers) can be very intense. Thus, concentration is "the most striking feature of the geography of economic activity" (Krugman 1991, p. 5; see also Hippe 2014, Baten and Hippe 2018, Diebolt and Hippe 2018, 2019)[6]. However, ICTs may well reduce agglomeration forces by allowing many forms of contacts without requiring spatial proximity and, as noted by Graham and Marvin (1996, p. 326), "utopian and technology determinists point to the dissolution of the city".

The history of the telegraph shows that this technology has indeed played a role in the dispersion of activities, by allowing a separation between offices and industrial plants, between headquarters and manufacturing processes. As highlighted by Tarr et al (1987), few data exist however to show to what extent the telegraph actually contributed to the decentralization of productive facilities. It is worth noting indeed that the telegraph's utility was limited by many factors as a communication device such as its cost or the inability to use it to engage in discourse. The telegraph prepared the way for the more flexible telephone and, ultimately, newest ICTs that facilitated further the dispersion of activities across the globe.

Even though ICTs have contributed to the dispersal of some activities away from the city, they have not led to its disintegration. On the opposite, the telephone first further increased the concentration of activities in the centre of cities with an unclear impact on transport needs. As pointed out by Pool et al (1977), before the telephone, businessmen needed to locate close to their business contacts: every city had a hatters' neighbourhood, a fish market, a financial district, etc. Businessmen would pay a great deal for an office within a few blocks of their trade centre and, once the telephone was available, they could move to cheaper quarters while still keeping in touch. Then, at an early stage the telephone helped dissolve the solid knots of traditional business neighbourhoods and helped create large new downtowns. Interestingly, this association was initially not anticipated by contemporaries.

[6] Theorists such as Fujita and Krugman (2004) list a number of standard forces that lead to agglomeration or dispersion of firms and workers in space. Among dispersion forces, one may quote the land and housing prices that are lower in the countryside than in a city or commuting that enables individuals to live at considerable distance from their workplace. Main agglomeration forces are the beneficial contacts between consumers, producers and suppliers of goods, which are improved by spatial proximity, or the positive externalities that may arise from locating near other actors of the same sector and thus being in contact with the knowledge of others.

Strikingly, the relationships change with time and the level of telephone penetration. Although initially the telephone facilitated the growth of cities, "a parallel trend was also developing". That second trend was a dispersion from the city "to suburbia and exurbia" (Pool 1983, p. 453), with a massive impact on mobility needs. Dispersal was initially based on more efficient transport systems (mostly automobile and highways), which helped minimise the travel time especially associated with commuting. But the "ability to pick up a telephone and get a message through without moving was just essential as the car" (Pool 1983, p. 454).

3.4 ICT and the "electronic cottage"

We have already seen above that ICTs have raised and keep raising hopes that people could work and have access to many goods or services without having to travel anymore. At the same time, ICTs have also raised social concerns that people might end up isolated in their "electronic cottage". What lessons can we draw from the history of ICTs?

It turns out indeed that teleworking, which has expanded since the start of the COVID-19 pandemic (Pouliakas 2020, Pouliakas and Branka 2020) and particularly for ICT professions (Flisi and Santangelo 2022), is not a new idea. As highlighted by England (2004, p. 272), "a US bank manager strung a telegraph line to his home so he could work at weekends almost as soon as the telegraph was invented". Neither is teleshopping: rail and telegraph made possible the development of catalogue sales (Tedlow 1996), and the diffusion of household telephones further expanded its growth. But the fear of "electronic cottages" has not materialized (yet).

Whereas some expected the telephone to substitute physical contacts, it turns out that the relationship between personal communication and mobility is much more complex. This is best illustrated by the first phrase that was spoken on the phone by its inventor Bell. He said: "Mr. Watson, come here; I want you" (Mokhtarian 2002, p. 45).

4. "New" ICT and the reduction in mobility needs

Many authors predict a radical change in the geography of activities because of "new" ICT. Audirac (2005) assesses that cities will not be monocentric with one important cluster, but polycentric, and that the future metropoles will be more widely spread out and intensively interconnected by ICT and transportation with still important traffic. On the other hand, Cohen-Blankshtain and Rotem-Mindali (2014) see a further tendency towards concentration of activity that is linked to accessibility and connectivity.

Whatever the new geography of activities, one of the promises of ICT for mobility identified in section 2 is the reduction in transport needs for individuals through new systems of tele-working, tele-shopping or tele-leisure. This effect is commonly called the substitution effect. This would mean that there is a fixed amount of functions performed by the use of ICT and transportation, so that an increase in one variable necessitates a decrease in the other (Plaut 1997).

Alternatively, ICT and transportation may also be complementary. This means that an increase in the use of ICT (or the invention of new ICT) will have a positive effect on the propensity to travel. Contrary to the substitution hypothesis, the volume of transactions is not seen to be fixed but variable, so that it may increase through more ICT or more travel. For example, the flexibility of working (in part) at home may incentivise workers to choose a location of their home farther away from their work than they would if they had to go to work every day. In more extreme cases, individuals can even live in other countries than their employer, communicate by the use of different ICTs (e.g., emails, videoconferencing, etc.), and fly over thousands of kilometres once or twice a month.

For a number of years, most researchers have focused on the substitutes versus complements debate. Even if communication and transportation have both grown massively over the last centuries pushing people to think there is an overall complementarity between these two dimensions (see below), it turns out that there may be substitution in some fields of transportation. Adopting a micro-perspective, researchers have often made the distinction between three different trip purposes: subsistence (e.g., work), maintenance (e.g., shopping) and leisure (Mokhtarian et al 2006). Special interest has been given to the corresponding emerging tele-modes, that is tele-commuting, tele-shopping and tele-leisure. Cohen-Blankshtain and Rotem-Mindali (2014) review the literature on the effects of these new modes. First, evidence of tele-commuting (or tele-working) appears to show a substitution effect (e.g., Pendyala et al 1991, Balepur et al 1998), which is smaller than often anticipated (Mokhtarian and Salomon 2002). However, it is not a pure substitution effect, as there are also relevant complementary effects. For example, business networks become larger and necessitate increased travelling. Still, this effect is smaller than the substitution of working, for example, at home. Evidently, more recently, the COVID-19 crisis has put the substitution debate much more in the public focus, as many workers around the world have been inhibited to go to work and had to stay at home due to lockdown restrictions (Bick et al 2020, Diebolt and Hippe 2022, Jakubowski et al 2022). Indeed, this has led to a large-scale forced substitution between offline and online work (Bartik et al 2020, Brynjolfsson et al. 2020, Mueller-Langer and Gomez-Herrera 2022). Those workers that were forced by the pandemic to work from home are also more likely to choose this option in the aftermath of COVID-19 (Kong et al 2022). At the same time, online labour markets have surged already before the crisis (Kässi and Ledhonvirta 2018) and are substituting offline jobs, while not having an impact on overall employment (Mueller-Langer and Gomez-Herrera 2022).

Second, tele-shopping is often considered to replace normal shopping because individuals increasingly shop digitally. Indeed, online shopping has been found to have substitution effects on in-store shopping (e.g., Anderson et al 2003, Fichter 2003, Mokhtarian 2004). This has also the effect of increased home deliveries and thus higher freight transport (e.g., Cohen 2000, Nemoto et al 2001). Still, a range of studies tend to show an overall limited or neutral impact on the combined personal and freight travel (e.g., Keskinen et al 2001, Visser and Lanzendorf 2004). On the one hand, a part of shopping trips are simply done not as an exclusive aim of a trip, but rather alongside other affairs. At the same time, many purchases can be done within one single trip. The fact that shopping opportunities become more transparent online also gives increasing incentives to travel to formerly unknown and perhaps distant shops (Farag et al 2006). More recently, Le et al (2022) provide an updated literature review, indicating that they found more evidence for the substitution effect.

Finally, tele-leisure activities imply that one can entertain oneself easily at home and does not need to travel for it. However, leisure activities are very diverse in nature. According to Cohen-Blankshtain and Rotem-Mindali (2014), the evidence of substitution or complementarity effects is mixed, in part because the results depend on the kind of the considered leisure activity. The results for leisure are not trivial, as between one third and one half of all personal trips are related to it (Mokhtarian et al 2006). Once again, COVID-19 and lockdown restrictions have also left their mark on these activities. They have increased strongly since the start of the pandemic, as individuals were less able to leave their homes (Marcucci et al 2021, Mouratidis 2021, Mouratidis and Papagiannakis 2021, Pierce et al 2021).

While the substitution vs complementarity debate has been popular in the past, it turns out that the relationship between ICT and mobility is more complex. The use of an ICT does not simply lead to more or less mobility: it modifies the way people move through space. For example, while a telephone call or the use of mobile Internet applications may not cancel a trip or lead to a new trip, they may modify the time or route or potentially the destination. Furthermore, while the direction of influence is often considered to run from ICT to transportation, one has to keep in mind that the impact may also be the other way round, i.e. that transportation may have a positive influence on ICT as well. For example, good pre-existing transport networks may be a positive stimulus to the development of ICT networks and technologies. One should also always bear in mind that there may be a neutral effect, i.e. no effect of ICT on mobility. Finally, although communication and mobility have closed relationships, one should not forget that there are many forces driving the rise in transportation other than communication, and vice versa. As discussed above, the massive increase in the daily travel distance of Americans – from 50 metres in 1800 to 50 kilometres nowadays – is mostly driven by the increasing speed of transportation systems from walking to automobile and rail.

5. Conclusion

Information and Communication Technologies (ICTs) have been hailed to generate a new world of prosperity, growth and sustainable development. However, we do not live in a brave new world where everything that we see has never been experienced before. While the newest ICTs such as the Internet are in some respects unique, in other respects they have historical predecessors such as the telegraph or the telephone that have generated important expectations and impacts on its contemporaneous society and mobility regime.

The literature review in this paper shows that ICTs have transformed and keep on transforming our economies and societies in very massive, long and unpredictable ways. The COVID-19 crisis is just one of the most recent examples which underlines this point more than ever, having led to a rise of teleworking which is here to stay to a relevant extent in many sectors. If one does not live yet in “electronic cottages”, as expected by some already a long time ago, “old” ICTs have modified radically our mobility by supporting and making more efficient new transport modes, by contributing to the geographical concentration and dispersion trends of cities and economic activities and by changing how and how much we connect to our families and friends. The interactions between mobility and ICT, be it new or older ICTs, turn out to be very diverse and complex.

However, in particular the literature on the historical interconnections between ICTs and mobility is still not well developed. Rather surprisingly, the related literature lacks a more detailed and thorough understanding of the complexity of these connections, including the creation of a broader range of data and statistics. While there are recent efforts to provide more data on the evolution of ICT and to put it into context (e.g., Lampe and Ploeckl 2014, Fouquet and Hippe 2019), more needs to be done, not only for ICT but also for mobility. Most importantly, linking historical ICT and transportation data and analysing the specific context and environments of their interactions needs more research. In addition, the literature at the crossroad of ICT and mobility histories does not provide much new to the analysis of "new" ICT impacts on sustainability, if only because this literature is poor.

If the current ICT wave put forward opens many opportunities for building a new (and more sustainable) mobility system, it also raises many challenges. For example, worldwide electronic information industry has been producing as much CO_2 as the aviation industry (Zhang and Xie 2015). At the same time, higher levels of teleworking may have positive consequences on short-run CO_2 emissions due to lower commuting needs, but long-term decisions may lead to relocation of tele-workers to less expensive suburbs, implying longer commutes, which in turn may more than offset this effect in the long run (Marz 2022). At the same time, ICTs have a positive impact on energy efficiency and decrease energy intensities (Fouquet and Hippe 2019), and communication transitions have been shown to be significantly faster than energy transitions in the European economies (Fouquet and Hippe 2022). This is particularly relevant as the European Commission has unveiled in May 2022 its REPowerEU plan to lower energy dependency from Russia, and boost renewable energies (European Commission 2022b). One of the key objectives is to further accelerate decarbonisation, including in the 'hard-to-decarbonise' transport sector. More is to come, as the European Commission has announced with its plan a future "Greening of Freight Package", which has the aim to safe energy, improve energy efficiency and speed up the transition towards emission-free vehicles (European Commission 2022c). Thus, overall, the creation and uses of different ICTs by itself can contribute to Climate Change, while in the long run it could still enable a new economic regime which can counteract it.

At the same time, the challenges posed by high rates of urbanisation, particularly in developing countries, are immense. For instance, while 400 million Africans were residing in cities in 2010, this number is forecasted to rise to 1.3 billion by the middle of the century (UN Desa 2014, Cobbinah et al 2015). Globally, while 50 % of the worldwide population was living in cities in 2008, it is projected to reach 70 % by mid-century (Albino et al 2013). In other words, there will be massive changes in the geographical distribution of the population in many continents, with huge impacts on the socio-economic and environmental regimes.

In addition, social distancing measures imposed by the COVID-19 pandemic around the world have put into the spotlight the need for multimodal transport systems which may boost resilience, affordability and sustainability of transportation (Amekudzi-Kennedy et al 2020, Rupani et al 2020, Kong et al 2022). In addition, the concept of 'Smart Cities', which can be defined as cities "with a great presence of ICT" (Albino et al 2013, p.

1728)[7], is proposed to help alleviate some of these major challenges, although it has also faced a range of criticism (for a discussion see Martin et al 2018).

The 'human' part of these Smart Cities requires increasing the levels of education, or more broadly, human capital (see also Diebolt and Hippe 2019, Hippe and Fouquet 2019). Also in this case, ICTs in the form of mobile phones, tablets or other electronic hard and software may provide great opportunities for improving learning in schools – and policy makers are increasingly taking action in this direction. For example, the European Commission has recently set up the Digital Education Action Plan 2021-2027 (European Commission 2020), which aims at fostering digital education and skills in Europe and elsewhere. The need for it is huge, as the demand for advanced IT and basic digital skills is forecasted to rise in Europe by 91 % and 69 %, respectively, until 2030 (McKinsey Global Institute 2018). Thus, the European Commission has initiated also innovative and ambitious projects such as SELFIE, a new self-reflection tool which is available to schools worldwide. SELFIE supports educational organisations in introducing and implementing digital technologies for teaching and learning and ultimately in making future generations fit for the digital age (Broek and Buiskool 2020, Castaño Muñoz et al 2021, Hippe et al 2021, JRC and ETF 2021, Jakubowski and Hippe 2022). With more than 2.7 million users worldwide, it supports more than 20,000 schools that want to move forward in using digital technologies after ad-hoc emergency response teaching during COVID-19 (European Commission 2022d). The EU Agency Cedefop has also recently released resources to support integrating and bolstering digital tools (Cedefop 2022a) and will soon publish an overview of recent digital education projects specifically in vocational education and training (Cedefop 2022b).

Still, for ICTs to drive a new and more sustainable mobility and beyond that a more sustainable society, there are plenty of conditions to be met and of choices to be made, individually or collectively. This calls for integrating all the new options permitted by ICTs into mobility policies and governance, analyzing their potential realistically. Generally speaking, ICT is a powerful engine to transform how we move and live but this engine has to be given a direction. As Perez (2014, p. 11; p. 12) puts it: "the particular trajectory followed by a technological revolution is not endogenously determined only. All that a technological potential can do is set the stage for the social actors to take their decisions and shape the favored direction from within the new range of the viable"; "social values, policies, regulations, taxes, costs and relative prices will be the ultimate drivers of the speed and depth of the shift."

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[7] The concept is described in more detail by Marsal-Llacuna et al (2015, p. 621): "the Smart Cities initiative seeks to improve urban performance by using data, information and Information Technologies (IT) to provide more efficient services to citizens, to monitor and optimize existing infrastructure, to increase collaboration between different economic actors and to encourage innovative business models in both the private and public sectors".

References

Albino V, Berardi, U and Dangelico RM (2013). Smart cities: Definitions, dimensions, and performance, in: Smart Growth: Organizations, Cities and Communities. Proceedings of the 8th International Forum on Knowledge Asset Dynamics, Matera, Italy: Institute of Knowledge Asset Management, 1723-1738.

Amekudzi-Kennedy A, Labi S, Woodall B, Chester M, Singh P (2020). Reflections on Pandemics, Civil Infrastructure and Sustainable Development: Five Lessons from COVID-19 through the Lens of Transportation. Preprints, 2020040047 (doi: 10.20944/preprints202004.0047.v1).

Anderson WP, Chatterjee L and Lakshmanan TR (2003). E-commerce, transportation, and economic geography, Growth and Change, 34 (4): 415-432.

Audirac I (2005). Information technology and urban form: challenges to smart growth, International Regional Science Review, 28 (2): 119-145.

Balepur PN, Varma KV and Mokhtarian PL (1998). The transportation impacts of center-based telecommuting: interim findings from the Neighborhood Telecenters Project, Transportation, 25 (3): 287-306.

Banister D (2014). Innovation in mobility: combining vision, technology and behavioural change, in: Grosclaude JY, Pachauri RK and Tubiana L (eds.), Demailly D, Jozan R and Sundar S (assoc. eds.). A Planet for Life, Teri Press.

Banister D (2008). The sustainable mobility paradigm. Transport policy, 15 (2): 73-80.

Bartik AW, Bertrand M, Cullen Z, Glaeser EL, Luca M and Stanton C (2020). The impact of COVID-19 on small business outcomes and expectations. *Proceedings of the national academy of sciences*, 117(30): 17656-17666.

Baten J and Hippe R (2018). Geography, land inequality and regional numeracy in Europe in historical perspective, *Journal of Economic Growth*, 23(1): 79-109.

Berkhout F and Hertin J (2001) Impacts of Information and Communication Technologies on Environmental Sustainability: speculations and evidence, report to the OECD, http://www.oecd.org/sti/inno/1897156.pdf.

Bick A, Blandin A and Mertens K (2020). Work from Home After the COVID-19 Outbreak, Federal Reserve Bank of Dallas Working Paper 2017.

Broek S and Buiskool BJ (2020). *Adapting the SELFIE tool for work-based learning systems in Vocational Education and Training. A feasibility study*. Hippe R and Kampylis P (eds.). EUR 30079 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-10623-4, doi:10.2760/934724, JRC119707.

Brynjolfsson E, Horton JJ, Ozimek A, Rock D, Sharma G and TuYe HY (2020). COVID-19 and remote work: An early look at US data (No. w27344). National Bureau of Economic Research.

Carey JW (2009). Communication as Culture, Revised Edition: Essays on Media and Society, New York: Routledge.

Castaño Muñoz J, Costa P, Hippe R and Kampylis P (2018). Within-school differences in the views on the use of digital technologies in Europe: evidence from the SELFIE tool, in: EDULEARN18 Proceedings, IATED Academy, 10417-10426.

Castaño Muñoz J, Vuorikari R, Costa P, Hippe R and Kampylis P (2021). Teacher collaboration and students' digital competence-evidence from the SELFIE tool. European Journal of Teacher Education, 1-22.

Cedefop (2022a). Digital inclusion, https://www.cedefop.europa.eu/en/tools/vet-toolkit-tackling-early-leaving/intervention-approaches/digital-inclusion.

Cedefop (2022b). Teachers and trainers in a changing world: synthesis report, forthcoming.

Choo S and Mokhtarian PL (2007). Telecommunications and travel demand and supply: Aggregate structural equation models for the US, Transport Research A, 41: 4-18.

Cobbinah, P. B., Erdiaw-Kwasie, M. O., & Amoateng, P. (2015). Rethinking sustainable development within the framework of poverty and urbanisation in developing countries. Environmental Development, 13: 18-32.

Cohen N (2000). Greening the Internet: Ten ways e-commerce could affect the environment, Pollution Prevention Review, Winter, 13-29.

Cohen-Blankshtain G and Rotem-Mindali O (2013). Key research themes on ICT and sustainable urban mobility, International Journal of Sustainable Transportation, DOI: 10.1080/15568318.2013.820994.

Demailly D and Verley P (2013). The aspirations of the green industrial revolution: a historical perspective, IDDRI Working Papers No. 11/2013.

Diebolt C (2002). Towards a New Social Structure of Accumulation?, Historical Social Research. An International Journal for the Application of Formal Methods to History, 27 (2/3): 85-99.

Diebolt C (2005). Long Cycles Revisited. An Essay in Econometric History, Economies et Sociétés, Série AF, 32: 23-47.

Diebolt C (2012). Cliometrics of Economic Cycles in France, Kondratieff Waves, 120th Anniversary of Nikolai Kondratieff's Birth, 1: 120-137.

Diebolt C (2021). Trend, Cycles and Chance. Kondratieff Waves, 5: 190-198.

Diebolt C and Hippe R (2018). Remoteness equals backwardness? Human capital and market access in the European regions: insights from the long run, Education Economics, 2018, 26 (3): 285-304.

Diebolt C and Hippe R (2019). The long-run impact of human capital on innovation and economic development in the regions of Europe. Applied Economics, 51 (5): 542-563.

Diebolt C and Hippe R (2022). Human Capital and Regional Development in Europe. A Long-Run Comparative View, Springer.

Dilts MM (1941). The telephone in a changing world, New York: Longman's Green.

Eichengreen, B. (2014). Hall of mirrors: The great depression, the great recession, and the uses-and misuses-of history. Oxford University Press.

England B (2004). Teleworking: Work From Afar, in: Spoonley P, Dupuis A and De Bruin A (eds). Work and Working in Twenty-first Century New Zealand, Palmerston North: Dunmoore Press.

European Commission (2019). The European Green Deal, COM(2019) 640 final.

European Commission (2020). Communication on the Digital Education Action Plan 2021-2027, https://ec.europa.eu/education/sites/default/files/document-library-docs/deap-communication-sept2020_en.pdf.

European Commission (2022a). Press statement by President von der Leyen on the Commission's proposals regarding REPowerEU, defence investment gaps and the relief and reconstruction of Ukraine, https://ec.europa.eu/commission/presscorner/detail/en/statement_22_3164.

European Commission (2022b). REPowerEU Plan, COM(2022) 230 final.

European Commission (2022c). REPowerEU: A plan to rapidly reduce dependence on Russian fossil fuels and fast forward the green transition, 18 May 2022, https://ec.europa.eu/commission/presscorner/detail/en/ip_22_3131.

European Commission (2022d). SELFIE, https://schools-go-digital.jrc.ec.europa.eu/.

European Commission's Market Observatory for Energy (2010). Europe's energy position. Markets and supply, https://www.energy.eu/publications/KOAE09001_002.pdf.

European Parliament (2020). Transport CO2 emissions in focus, https://www.europarl.europa.eu/RegData/etudes/ATAG/2020/659265/EPRS_ATA(2020)659265_EN.pdf.

Farag S, Weltevreden J, van Rietbergen T, Dijst MT and van Oort F (2006). E-shopping in the Netherlands: does geography matter?, Environment And Planning B – Planning & Design, 33(1): 59-74.

Fichter K (2003). E-Commerce: Sorting Out the Environmental Consequences, Journal of Industrial Ecology, 6(2): 25-41.

Fischer C (1988). Touch Someone: The Telephone Industry Discovers Sociability, Technology and Culture, 29 (1): 32-61.

Flisi S and Santangelo G (2022). Occupations in the European Labour Market During the COVID-19 Pandemic, *Intereconomics*, 57: 120–126, https://doi.org/10.1007/s10272-022-1040-y

Fouquet R and Hippe R (2019). The Transition from a Fossil-Fuel Economy to a Knowledge Economy, in Fouquet, R. (ed.) Handbook on Green Growth. Edward Elgar Publications. Cheltenham, UK, and Northampton, MA, USA.

Freeman C Ed (1996). *Long Wave Theory*, Cheltenham: E. Elgar.

Fujita M and Krugman PR (2004). The new economic geography. Past, present, and the future, Papers in Regional Science, 83: 139-164.

Geels FW and Smit WA (2000) Failed technology futures: pitfalls and lessons from a historical survey, Futures, 32: 867-885.

GeSI (2012). GeSI SMARTer2020, http://gesi.org/portfolio/report/72.

Graham S and Marvin S (1996). Telecommunications and the city, London: Routledge.

Green E and Adam A (1998). On-line leisure: Gender, and ICTs in the home. Information Communication & Society, 1 (3): 291-312.

Grübler A (1990). The rise and fall of infrastructures, Heidelberg: Physica-Verlag.

Hippe R (2014). Human capital and economic growth: Theory and quantification. Economies et Sociétés, Série AF, 49: 1233-1267.

Hippe R and Fouquet R (2019). The human capital transition and the role of policy, in: Diebolt C and Haupert M (eds.). Handbook of Cliometrics, 2nd edition, Springer.

Fouquet R and Hippe R (2022). Twin Transitions of Decarbonisation and Digitalisation: A Historical Perspective on Energy and Information in European Economies, Working Paper.

Hippe R, Brolpito A and Broek S (2021). SELFIE for work-based learning. EUR 30836 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-41928-0, doi:10.2760/336883, JRC126317.

Jakubowski M and Hippe R (2022). What shapes student digital competence? Schools or individual factors? Insights from SELFIE using multilevel models, Cedefop Working Paper, forthcoming.

Jakubowski M, Hippe R and Pokropek A (2022). The impact of school closures on education during the COVID-19 pandemic: evidence from SELFIE using difference-in-differences, Working Paper.

JRC and ETF, Bocconi S and Lightfoot M with Brolpito A, Giannoutsou N, Hippe R and Kampylis P (2021). Scaling up and integrating the SELFIE tool for schools' digital capacity in education and training systems, European Training Foundation, Turin.

Kässi O and Lehdonvirta V (2018). Online labour index: Measuring the online gig economy for policy and research. *Technological forecasting and social change*, 137: 241-248.

Keskinen A, Delache X, Cruddas J, Lindjord JE and Iglesias C (2002). A Purchase and a Chain. Impacts of E-commerce on Transport and the Environment, Paris: OECD/ECMT.

Kleinknecht A (1987). *Innovation Patterns in Crisis and Prosperity. Schumpeter's Long Cycle Reconsidered*, London: The Macmillan Press Ltd.

Kondratieff N.D (1926). Die langen Wellen der Konjunktur, *Archiv für Sozialwissenschaft und Sozialpolitik*, 56: 573-609.

Kong X, Zhang A, Xiao X, Das S and Zhang Y (2022). Work from home in the post-COVID world. Case Studies on Transport Policy, in press, https://doi.org/10.1016/j.cstp.2022.04.002.

Krugman PR (1991). Geography and Trade, Cambridge: MIT Press.

Lampe M and Ploeckl F (2014). Spanning the Globe: The Rise of Global Communications Systems and the First Globalisation. Australian Economic History Review, 54(3): 242-261.

Le HT, Carrel AL and Shah H (2022). Impacts of online shopping on travel demand: a systematic review. *Transport Reviews*, 42(3): 273-295.

Lieberman (2018). In Good Times Prepare for Crisis: From the Great Depression to the Great Recession: Sovereign Debt Crises and Their Resolution. Brookings Institution Press.

Marcucci E, Gatta V, Le Pira M, Chao T and Li S (2021). Bricks or clicks? Consumer channel choice and its transport and environmental implications for the grocery market in Norway. *Cities*, 110: 103046.

Marsal-Llacuna ML, Colomer-Llinàs J and Meléndez-Frigola J (2015). Lessons in urban monitoring taken from sustainable and livable cities to better address the Smart Cities initiative. Technological Forecasting and Social Change, 90: 611-622.

Martin CJ, Evans J and Karvonen A (2018). Smart and sustainable? Five tensions in the visions and practices of the smart-sustainable city in Europe and North America. Technological Forecasting and Social Change, 133: 269-278.

Marvin C (1988). When old technologies were new, New York: Oxford University Press.

Marz W (2022). Reduziert mehr Homeoffice die Emissionen im Verkehr?, ifo Institut, München, ifo Schnelldienst, 2022, 75, Nr. 05, 15-18.

McKinsey Global Institute (2018). Skill Shift, Automation and the future of the workforce, Discussion Paper May 2018, https://www.mckinsey.com/featured-insights/future-of-work/skill-shift-automation-and-the-future-of-the-workforce?cid=soc-web

Mensch G (1977). *Das technologische Patt. Innovationen überwinden die Depression*, Frankfurt am Main: Fischer Taschenbuch Verlag.

Miroux F and Lefèvre B (2012). Mobilité urbaine et technologies de l'information et de la communication (TIC) : enjeux et perspectives pour le climat, IDDRI study no. 05/12.

Mok D, Wellman B, and Carrasco J (2010). Does distance matter in the age of the Internet?. Urban Studies, 47 (13): 2747-2783.

Mokhtarian PL (1990). A typology of relationships between telecommunications and transportation, Transport Research A, 24A (3): 231-242.

Mokhtarian PL (2002). Telecommunications and travel. The case for complementarity, Journal of Industrial Ecology, 6 (2): 43-57.

Mokhtarian PL (2004). A conceptual analysis of the transportation impacts of B2C e-commerce, Transportation, 31(3): 257-284.

Mokhtarian PL (2009). If telecommunication is such a good substitute for travel, why does congestion continue to get worse?, Transportation Letters, 1: 1-17.

Mokhtarian PL and Salomon I (2002). Emerging travel patterns: Do telecommunications make a difference?, in: Mahmassani HS (ed.). In Perpetual Motion: Travel Behaviour Research Opportunities and Application Challenges. Oxford: Pergamon Press, 143–182.

Mokhtarian PL, Salomon I and Handy SI (2006). The impacts of ict on leisure activities and travel: a conceptual exploration, Transportation, 33: 263-289.

Morus IR (2000). 'The Nervous System of Britain': Space, Time and the Electric Telegraph in the Victorian Age, The British Journal for the History of Science, 33 (4): 455-475.

Mouratidis K (2021). How COVID-19 reshaped quality of life in cities: A synthesis and implications for urban planning. *Land Use Policy*, 111: 105772.

Mouratidis K and Papagiannakis A (2021). COVID-19, internet, and mobility: The rise of telework, telehealth, e-learning, and e-shopping. *Sustainable Cities and Society*, 74: 103182.

Mueller-Langer, F., & Gomez-Herrera, E. (2022). Mobility restrictions and the substitution between on-site and remote work: Empirical evidence from a European online labour market. *Information Economics and Policy*, *58*, 100951.

Nemoto T, Visser J and Yoshimoto R (2001). Impacts of Information and Communication Technology on Urban Logistics System, OECD/ECMT.

Pendyala RM, Goulias KG and Kitamura R (1991). Impact of telecommuting on spatial and temporal patterns of household travel, Transportation, 18 (4): 383-409.

Perez C (2014). A Green and Socially Equitable Direction for the ICT Paradigm, Chris Freeman Memorial Lecture, GLOBELICS 2012, Hangzhou, P.R. China, Globelics Working Paper No. 2014-01.

Pierce BS, Perrin PB, Tyler CM, McKee GB and Watson JD (2021). The COVID-19 telepsychology revolution: A national study of pandemic-based changes in US mental health care delivery. *American Psychologist*, 76(1): 14.

Plaut PO (1997). Transportation-communications relationships in industry, Transport Research A, 31 (6): 419-429.

Pool I de Sola (1977). The Social Impact of the Telephone, Cambridge: MIT Press.

Pool I de Sola (1983). Forecasting the Telephone: A Retrospective Technology Assessment, Ablex Publishing: Norwood.

Pouliakas, K (2020). Working at Home in Greece: Unexplored Potential at Times of Social Distancing?, IZA Discussion Papers, No. 13408, Institute of Labor Economics (IZA), Bonn.

Pouliakas, K and Branka J (2020). EU jobs at highest risk of Covid-19 social distancing: Is the pandemic exacerbating the labour market divide?, Publications Office of the European Union, Cedefop working paper, 1.

Pred A (1973). Urban Growth and the Circulation of Information, Cambridge, MA: Harvard University Press.

Rifkin J (2011). The Third Industrial Revolution: How the Internet, Green Electricity, and 3-D Printing are Ushering in a Sustainable Era of Distributed Capitalism, New York: Palgrave Macmillan.

Rupani PF, Nilashi M, Abumalloh RA, Asadi S, Samad S and Wang S (2020). Coronavirus pandemic (COVID-19) and its natural environmental impacts, *International Journal of Environmental Science and Technology*, 17(11): 4655-4666.

Sassen S (2012). Cities in a World Economy, Thousand Oaks: Pine Forge Press.

Schumpeter J.A (1939). *Business Cycles. A Theoretical, Historical and Statistical Analysis of the Capitalist Process*, 2 Vols, London: McGraw-Hill Book Co.

Spar DL (2001). Ruling the Waves: From the Compass to the Internet, a History of Business and Politics along the Technological Frontier, New York: Harcourt.

Standage T (1998). The Victorian Internet, London: Weidenfeld and Nicolson.

Tarr JA, Finholt T and Goodman D (1987). The City and the Telegraph Urban Telecommunications in the Pre-Telephone Era, Journal of Urban History,

Tedlow R (1996). New and improved. The story of mass marketing in America, Cambridge: Harvard University Press.

Temin, P. (2010). The great recession & the great depression. Daedalus, 139 (4): 115-124.

Thrift N (1990). Transport and Communication 1730-1914, in: Dodgshon RA and Butlin RA (eds.). An Historical Geography of England and Wales, London: Academic Press Limited.

UN Desa (2014). World urbanization prospects, the 2011 revision. Population Division, Department of Economic and Social Affairs, United Nations Secretariat.

Urry J (2007). Mobilities, Cambridge: Polity.

Visser EJ and Lanzendorf M (2004). Mobility and accessibility effects of b2c ecommerce: A literature review, Tijdschrift voor Economische en Sociale Geografie, 95(2): 189-205.

Wilenius M and Casti J (2015). Seizing the X-events. The sixth K-wave and the shocks that may upend it. Technological Forecasting and Social Change, 94: 335-349.

Zhang N and Xie H (2015). Toward green IT: modeling sustainable production characteristics for Chinese electronic information industry, 1980–2012. Technological Forecasting and Social Change, 96: 62-70.